THE QUIZZYHOTA LACCOLITE

E. H. L. SCHWARZ
Rhodes University College, Grahamstown, South Africa

EARLY REFERENCES

The first reference to this remarkable mountain that I can find is contained in a description of Kaffraria by the Rev. Francis Fleming:[1]

> But perhaps the most surprising and gigantic of these singular precipices, as yet known in Kaffraria, is that which rises on the south bank of the Great Kei River, about seven miles from the old military post of Fort Warden and lying fifty miles north of King Williamstown. It forms one side of a singular shaped mountain, the Quizzyhota.[2] The top is a long table-land of some miles in length, but contracted to about one or perhaps less in width. The extremities of the mountain and of the krantz which forms the whole north side of it and which is thickly covered with aloes, euphorbias and orchids, rise suddenly at angles of nearly 45°; the surrounding country stretching out into low undulating ground thinly dotted over with straggling mimosas and spec-boom, *Portulacaria afra*, gives an abrupt and most singular appearance to this object. On the southern side, which is thickly covered with large and thick bush, the hill descends with rather a more gradual slope and so affords an easy retreat for the Kaffirs.

For the purpose of visiting this singular locality a party of six officers left their quarters during the war of 1846. (Theal gives 13th November, 1847.) One of the number, however, feeling indisposed, left their party a short distance from the camp and returned home and so escaped the untimely end to which the other five poor fellows came. These unfortunate and deeply lamented officers were: Major William Leinster York Baker, Lieutenant Clarevaulx Faunt, Ensign William Burnop (Adjutant) and Doctor Neil Stewart Campbell of the 73rd Regiment, and Doctor R. J. Locke of the 7th Dragoon Guards. The author who visited the spot in person to superintend (by request) the removal of the bodies to King Williamstown, made every enquiry while there respecting them and their death scene. One Kaffir was shown to him who displayed a wound on his right side which he said he had received from one of the gentlemen

[1] *Kaffraria and Its Inhabitants*, London, Simpkin, Marshall & Co. (1854), 39.

[2] *Quizzyhota* is a Kaffir word meaning "the place where one warms one's hands." The name is particularly applicable to the mountain as the middle slopes consist of bare faces of dolerite which, exposed throughout the day to the sun, absorb the heat and become intensely hot.

(probably Major Baker) whom he described as fighting most gallantly to the last and only killed by overpowering numbers. The author has also every reason to conclude that all were killed there and then and that no previous torture of any kind was attempted by the Kaffirs.

Two days had passed before their bodies were discovered and brought to Sir George Berkeley's camp then pitched on the banks of the Komgha stream, a small tributary of the Kei, about ten miles from the spot where they fell. Here they were hastily interred in one grave, but in the month of August, 1850, only a few months before the present Kaffir outbreak, the bodies were fortu-

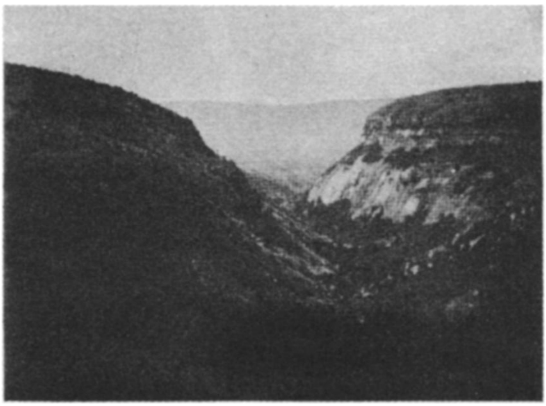

FIG. 1.—Etanga Valley from railway. The Quizzyhota, showing the horizontal Karroo rocks above and the bare faces of dolerite below.

nately removed and reinterred in an unmolested and shortly to be consecrated grave beneath the western tower of Trinity Church, now in course of erection at King.

The woodcut of the scene accompanying Mr. Fleming's account is taken from about the thirty-second milestone on the newly constructed Amabele–Butterworth railway; this, and the fact that the Quizzyhota faces northwest, clearly identify the actual scene of the slaughter. Locally the abrupt mountain opposite the Quizzyhota and separated from it by the gorge of the Etanga,[1] which forms a much more prominent landmark from the level of the river, is

[1] *Etanga* is a Kaffir word meaning a "place where the cows are kept." The best cows are kraaled round the huts, but the surplus are sent out to some sequestered place, usually inclosed, as this particular valley is, by inaccessible cliffs, so that by merely fencing the narrow opening the cattle are prevented from wandering.

called Mordenaars Kop or the Murderer's Hill, but this is clearly incorrect.

DESCRIPTION OF THE QUIZZYHOTA LACCOLITE

The laccolite extends some 3 miles along the Kei River and it can be traced for some 6 or 8 miles into the plateau on which the village of Komgha stands. The plateau is some 2,000 feet high; the village which lies in a slight hollow is 2,114 feet above sea-level; the bottom of the cliff is 500 feet, so that the height of the vertical

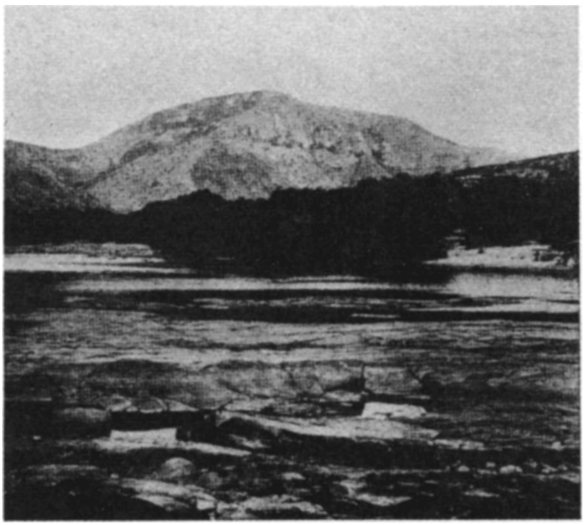

FIG. 2.—The western end of the Quizzyhota laccolite, showing the vertical faces of the dolerite on the north and the undisturbed Karroo rocks in front.

face of the laccolite is 1,500 feet. The laccolite ends along the river in a vertical face which, however, is seen only in the western end and then for only a part, as the undisturbed horizontal sedimentary beds form three-fourths of height of the hill. Down stream, on the east of the Etanga Valley, the dolerite is exposed nearly to the level of the river bed, but there is always a little foot of sediments between the dolerite and the river; here unfortunately weathering has degraded the vertical face of dolerite to a slope of about 30° covered with gigantic bowlders, and it is impossible, therefore, to give a photograph showing the entire face. The rock

readily splits up along joints when exposed on the surface, and even the fresh face on the west, where it is exposed above the sedimentary beds, has scaled to a depth of some 10 feet or so; and the slopes below are covered with scree formed of the fallen blocks.

Along the Etanga Valley the dolerite comes toward the Kei River with a covering of 100 feet of sediments, then just below the farmhouse, on top, the dolerite breaks through to a higher horizon; at the western end there remains a covering of sedimentary

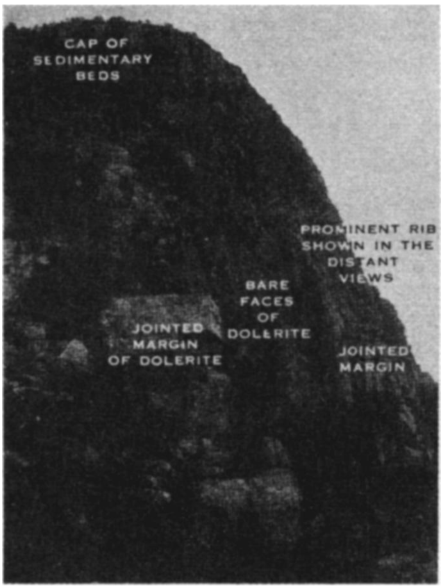

FIG. 3.—Western end of the Quizzyhota laccolite.

beds of about 30 feet thick, but on the Quizzyhota Hill the dolerite apparently reaches the summit. The line of demarkation where the dolerite impinges on the sedimentary rocks is exposed with extraordinary clearness on the krantz. The length of the laccolite along the river is cut twice by short valleys; the easternmost is the Etanga Valley, which is a deep fjord-like gorge that runs into the dolerite, doubtless along lines of original fracture which have been worked out by weathering. The valley forks into two branches about half a mile from the entrance. One of the branches

runs south and ends in a cul-de-sac surrounded by bare faces of dolerite; the other runs west. The bottom of the valley rises very gently and is about a hundred yards wide. It is surrounded everywhere by the dolerite; the new railway skirts the edge of the southern branch, and the view as one looks down into this cleft from the carriage window is most remarkable. The streams flowing down into the Kei from the escarpment of the plateau are very steeply graded, but here is a valley which begins at the head with a vertical wall 1,000 feet deep.

The laccolite is about three miles long from east to west, the exposed vertical side facing north, but there is a low-lying expansion of about 100 feet above the level of the river which is exposed in a cutting near the zig-zag of the railway, and this would add another mile to the length along the river. The faces of the main mass are quite vertical toward the river which comes almost due south to the laccolite, abuts against it, and follows its northern edge to the east. The sedimentary rocks are for the most part cleared away from the northern side. On the downstream end, above the hotel and road-bridge, the dolerite has been exposed for a long while and there is only a steep slope rising at an angle of 30°, studded with gigantic bowlders of dolerite, but for the rest grassy, with sparse mimosa trees. About two miles up the river is the Etanga Valley. On the west the dolerite rises in a magnificent vertical wall, capped with horizontal beds of sandstone for some 30 feet. On the outside of the vertical face there is a zone of much-jointed dolerite rising in pinnacles on either side of a sort of window of sedimentary rocks through which the vertical face appears. The pinnacles are the jointed outer margin of the laccolite. The dolerite to the west of this plunges into the sedimentary beds which form the walls of the valley of the Great Kei River lying almost at right angles to the northern face of the laccolite. In other words, the laccolite has barred the way of the river which flows at its foot, and the weathering that has allowed a small amount of sedimentary beds to remain plastered, as it were, on to the face of the laccolite on the west, has cleared all these away down stream on the east. In the same way the sedimentary beds form half the height of the hill on the west of the Etanga Valley, between the dolerite and the river, so that

at first sight it would appear that the actual base of the laccolite was exposed, but farther down stream the dolerite descends to the bed of the river. The sedimentary rocks in the bed of the river, though quite close to the dolerite, are unaltered and undisturbed.

The top of the laccolite spreads out to the south beneath the thin covering of sedimentary beds, perhaps reaching the village of Komgha which lies to the west-southwest about 10 miles from the bridge in a straight line (18 by railway). Three miles from the village, however, the railway skirts a shallow valley on the plateau which is covered with rich black soil, very different from the light sandy soil derived from the weathering of the sedimentary beds, which is good only for pasture lands; here, however, every inch is cultivated. This is the first exposure of dolerite which one can definitely connect with the Quizzyhota laccolite. The dolerite continues along the railway for 2 miles, then runs over the sedimentary covering for half a mile, and then again for about 200 yards is carried over the dolerite. Beyond, the railway cuttings are in the sedimentary beds forming a thin undisturbed covering to the laccolite, till the Etanga Valley is reached 2 miles farther on. Here the railway crosses the road at No. 6 railway cottage, and the plunge into the valley of the Kei begins. For a little distance the railway is cut in the eastern slope of the laccolite, which is here intensely weathered, the square jointed blocks having broken down into a brown sand, while in their centers there remain, in many cases, rounded blocks of quite unaltered rock. The blocks exposed in a similar position on the western end facing the river are jointed in the same way, but there is no evidence of the spheroidal weathering nor of the intense alteration. It appears that the intense crumbling is a consequence of the covering of sour soil which yields organic acids in large quantities and thus supplies a powerful solvent for the iron combined in the ferro-magnesian minerals. The finest example of the spheroidal weathering about here is in the great laccolite which lies 3 miles from Amabele Junction and which is exposed along the railway to within a few miles of Komgha village (27 miles from Amabele). Here the jointing is horizontal and vertical and every tenth block, more or less, has a solid unaltered core of grey dolerite. The weathered material can be dug with a spade and is

used extensively as fine gravel. The spheroidal weathering is noticed only on the outer margin of the laccolites. From the top of the Etanga Valley to the river level there is a drop of 1,500 feet; Komgha lies on the plateau at 2,114 feet above sea-level, and

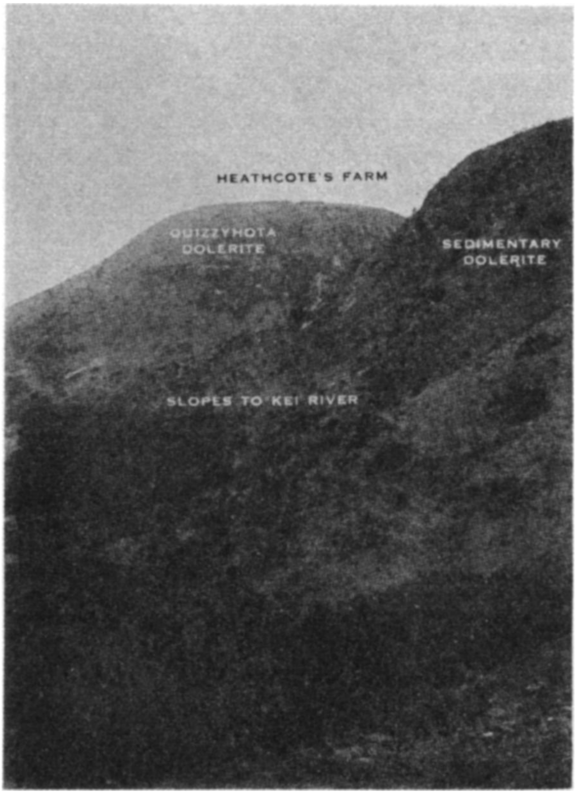

FIG. 4.—The Quizzyhota Mountain, showing the dolerite breaking up through the Karroo sedimentary beds. Looking east, i.e., down stream.

Sihota,[1] the station just on the Transkeian side of the bridge, at 560 feet. Sihota lies some 50 feet above the river. This drop of 1,500 feet is accomplished by the railway in 10 miles, or less than half that in a straight line, and just before entering the zig-zag by which the train reaches the level of the river there is a small expo-

[1] *Sihota* is a Kaffir word meaning an "ant-bear."

sure of dolerite in the cutting, which may belong to the main laccolite or may be a horizontal dyke proceeding from it, or may be quite an independent body; farther away there is an exposure of dolerite in the small valley crossed by the railway but the relationships of this and dolerite in the cutting are uncertain.

In the Amabele-Komgha laccolite the mass rears its head above the general level of the plateau which belongs to the 2,500-feet plateau[1] but which has been degraded by surface weathering some 300 to 400 feet. The Amabele-Komgha laccolite was below the level of the original plateau, although now its bald head is exposed; the Quizzyhota laccolite, on the other hand, is only just beginning to appear on the plateau, being for the most part hidden by the sedimentary beds.

THE SEDIMENTARY ROCKS INTRUDED BY THE QUIZZYHOTA LACCOLITE

The Sedimentary Beds cannot be placed in any definite scheme as yet. They consist of whitish or light grey-blue sandstones, fairly loose in grain, interbedded with blue shales, weathering yellow. They correspond to the Karroo Beds as exposed in the Free State and Transvaal and to which Dr. Molengraaff gave the name of "High Veld Series." Farther east, at Idutywa, the whiteness of the sandstones becomes more pronounced and the shales become brilliantly colored with red, purple, and blue tints, but the ordinary blue shales occur as well. Dr. Rogers and myself gave these beds the name of the "Idutywa Beds."[2] Subsequently Mr. Du Toit described the same beds from Queenstown and Burghersdorp districts as the "Burghersdorp Beds."[3] There seems no necessity to reduplicate names, and the term "Idutywa Beds" will be used here; eventually, if the connection is established with the Transvaal rocks, Molengraaff's term will have to be adopted. The suggestion to call them the *Cynognathus* beds, from the occurrence in them of this remarkable Theriodont reptile, does not appeal to

[1] E. H. L. Schwarz, "Coast Ledges in the South-West of Cape Colony," *Q.J.G.S.*, LXII (1906), 70.

[2] A. W. Rogers and E. H. L. Schwarz, "General Survey of the Rocks in the Southern Part of the Transkei and Pondoland, Including a Description of the Cretaceous Rocks of Eastern Pondoland." *Ann. Rept., Geol. Comm., 1901*, Cape Town (1902), 28.

[3] *Ninth Ann. Rept., Geol. Comm. 1904*, Cape Town (1905), 77.

me, because the fossils are extremely rare and localized, whereas the formation can be very clearly recognized by its lithological characters. Where the usual fine-grained blue sandstones of the Beaufort Beds proper give place to the coarser-grained white varieties, one can at once draw a line of division and map the latter as Idutywa Beds. The Idutywa Beds extend into the Western Karroo north of Laingsburg and far to the north in the Transvaal.

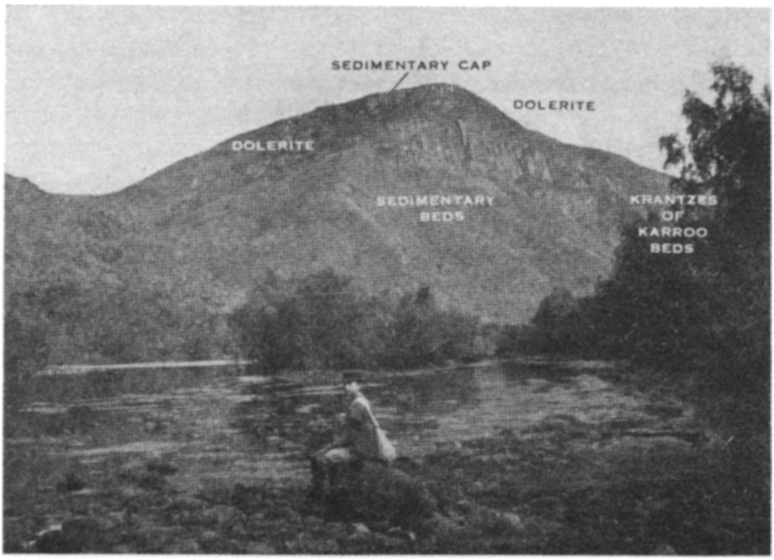

FIG. 5.—Western end of the Quizzyhota laccolite, showing the vertical face of the laccolite on the north and the sedimentary beds, plastered, as it were, onto the face, themselves quite undisturbed.

They once had a wider area of deposition than any other of the divisions of Karroo System.

Toward the middle of the descent of the Kei Hills the white sandstones disappear, and in their place there are the ordinary blue and blue-black shales, weathering olive-brown, which belong to the Beaufort Series. The normal sandstone banks of the formation farther west do not appear, probably because the weathering is so different. Here in the east, the country is a recently dissected plateau covered with grass and scored by deep ravines; in the west

the beds are exposed under arid conditions and the small differences of texture and hardness are very boldly shown on the faces of the kopjes. It may be that these differences are not sufficiently great to cause a separation into sandstones and shales in the sides of the ravines, where there is always a considerable amount of moisture. These beds were called by Dr. Rogers and myself the "Kentani Beds" in the report referred to above, and they were taken to be an

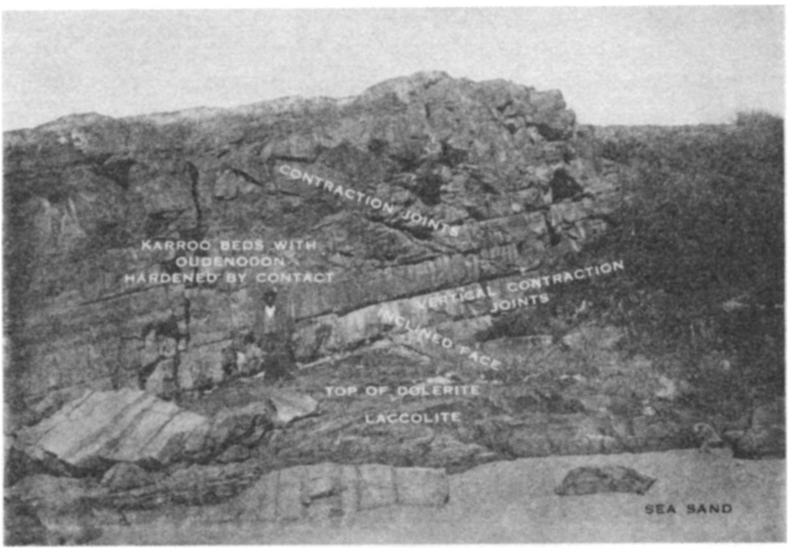

FIG. 6.—Top of laccolite, Mazeppa Bay, Kentani (just west of where the diorite dykes of the Transkei Gap run out to sea at the Koghe River mouth). The bleaching and hardening of the strata are well shown in the fallen blocks, where the bedding planes have become obliterated.

eastern facies of the Beaufort Beds. Dr. Rogers and myself obtained *Oudenodon* remains on the coast of Kentani, and there is an undescribed *Dicynodon* skull from Umtata in the Albany Museum belonging to the same horizon. The specimen was collected by Mr. E. J. Dunn; I submitted it to Mr. Watson, who informed me that the species was of the type found in the lower Beaufort Beds. On the Umkomazan River in Natal Dr. Broom[1]

[1] R. Broom, "Fossil Reptilian Remains from Natal," *Third Report Geological Survey of Natal and Zululand*, London, 1907.

described *Lystrosaurus*, which occurs on a higher horizon, but still within the Beaufort Series proper, so that these beds must occur in a strip running more or less north from East London, where again reptiles of the same horizon occur; but their development is not continuous. In Umsikaba (Flagstaff), in Eastern Pondoland, Dr. Rogers and myself found the Umsikaba Beds (the local facies of the Ecca Beds) directly followed by the Idutywa Beds. At the time, not knowing that the Kentani Beds wedged out, we placed the Idutywa Beds below the *Dicynodon* or Kentani Beds, thinking that they represented the *Pareiasaurus*—zone of the Beaufort Series; this was a natural mistake when working upward in the series, as there is a complete conformity between the Dwyka and Umsikaba (Ecca) Series and the Umsikaba and Idutywa Series. Later, however, working downward, we found the Molteno Beds of the Stormberg System lying directly on the Idutywa Beds.

Western Karroo	Eastern Districts	Pondoland	Transvaal
Idutywa Series	Idutywa Series	Idutywa Series	High Veld Series (Coal Measure Series)
Beaufort Series	Kentani Series	Wanting or only locally developed	Wanting
Ecca Series	Ecca Series	Umsikaba Series	Wanting
Dwyka Series	Dwyka Series	Dwyka Series	Dwyka Series.

PER SALTEM CONFORMITY

Such a conformity as that represented by the Umsikaba Series being followed by the Idutywa Series I will call a *per saltem* conformity. It is due to want of supply of sediment during some lengthened period. The most conspicuous example of it that we have in South Africa is the conformity between the Bokkeveld Series (lowermost Devonian) and the Witteberg Series (Lower Carboniferous), the whole of the Upper and Middle and most of the Lower Devonian being unrepresented. On the supposition that the fossils in South Africa have the same value as time markers as those in the northern hemisphere—which is a debatable point, but one which seems to become more definite as the material accumulates and the study of it advances—this conformity between the Witteberg and Bokkeveld Series is explained by the shore retreating

till detritus from land could no longer reach the particular locality; at the same time, owing to the violence of the currents or the coldness of the sea or for some other cause, the calcareous deposits in the deep ocean did not form, or, if they did form, were dissolved. Then when the sea-floor rose again and the shore advanced, sedimentation began once more, and the new deposits were laid down conformably on the older ones, although a considerable lapse of time had occurred between the two.[1] In the *per saltem* conformity between the Umsikaba and Idutywa Series we have other considerations to take into account. We are dealing with fresh-water deposits. In the Cape Colony proper, that is to say, in the central, south and west portions of the Great Gondwanaland Lake—Lake Union we might call it, as it embraced all the colonies united in the Union of South Africa, whereas the Karroo sediments of Rhodesia and farther north appear to have been deposited under independent sheets of water—the depth was greater and the sedimentation more extensive in the early Karroo times. This portion then filled up and the depression shifted up to the north and east. The hinge of the movement, if we can conceive the lake floors in the two periods as forming two planes meeting along a straight line, would run through Umsikaba (Flagstaff) in Pondoland and the deposits of the earlier depression would then be restricted to irregular arms and bays of the older lake and would form discontinuous pockets, as indeed they appear to do.

THE RELATIONSHIP OF THE DOLERITE TO THE SEDIMENTARY BEDS

It has been necessary to go into a little detail with regard to the sedimentary beds around the great Quizzyhota laccolite, because I seek to prove in the sequel that the dolerites are in part the product of the melting and absorption of the sedimentary beds. I have for many years been looking for a good example to work on, but there have been objections to all of them. The ordinary dykes of the Karroo are of no use, as it is impossible to prove that the space occupied by the igneous rock has been melted out by the dolerite. Immense laccolites occur in the center of the Karroo

[1] E. H. L. Schwarz, "South African Palaeozoic Fossils," *Records Albany Museum*, Vol. I, Grahamstown (1906), 360.

dolerite area in Fraserburg, and one of them furnishes an illustration appearing in Dr. Rogers' *Geology of Cape Colony*,[1] but the contacts are covered. In Burghersdorp, Cradock, and in Cathcart, at Turnstream, along the Great Kei River, there are admirable examples, but only the tops of the great domes appear and no estimate as to the size or shape can be arrived at. A very fine one occurs on the Kentani coast,[2] also exposed only along the extreme top, while the enormous ones of Mount Ayliff, Mount Currie, and others on the Drakensburg Plateau occur in the Molteno Beds and are doubtfully to be ascribed to the same system as the Karroo dolerites. The Quizzyhota laccolite, out of all I have seen in seventeen years' traveling in South Africa, is the best for the purpose I have in hand.

Wherever one finds Karroo sediments, especially those above the *Pareiasaurus* zone, there is usually intrusive dolerite. Again, where the Karroo sediments have been peeled off and the underlying Archaean or Cape system floor is exhibited, there are exceedingly few dykes and those that exist are puny, insignificant stringers as compared to the massive dykes and sills of the Karroo Beds which once lay above them. There is a good example of this to the east and west of Prieska. On the east a loop of the Orange River incloses a peninsula of Karroo shales with a great sill of dolerite. On the west the Griquatown (Pretoria) Beds form the Doornberg Hills, through which runs Prieska's Poort and Keikam's Poort. In both of these gorges thin, nearly vertical, dykes occur, but the main portion of the range is quite devoid of dolerite; yet, looking, to the south where the escarpment of the Karroo Beds begins practically a third of the height of the hills is occupied by dolerite. The occurrence of the dolerite-containing Karroo sediments to the west and south of the Doornberg proves that they were once continuous over the hills.

The question remains: Where did the dolerite come from if there are such feeble channels of supply in the older rocks? Did the Karroo sediments spontaneously melt? I shall seek to prove

[1] 1st ed., 279; 2d ed., 286.

[2] E. H. L. Schwarz, "Origin of the Rand Bankets," *Journal Assoc. for Advancement of Science, S. Africa*, VIII (Cape Town, 1912).

in the sequel that a considerable proportion of the Karroo dolerite is composed of the melted-up sediments, and that the accession of fresh molten material from the deeper portions of the crust was comparatively small in proportion to the amount exhibited on the surface.

THE GREAT KARROO LACCOLITE

All the dolerites of the Karroo—the sills and dykes of the main portion and the laccolites on the east—belong to one and the same system; they together form one immense laccolite of the type known as the "Cedar tree laccolite." The type was first described by Holmes on the La Plata Mountains of Colorado[1] and has since been noted in the gabbro of the Cuillin Hills of Skye,[2] but nothing like the stupendous nature of the Karroo laccolite occurs in other parts of the world. The Karroo laccolite is some 700 miles long by at least 200 miles broad; the great Transvaal laccolite, large as it is, is only 250 miles long. The dolerite sills form generally in the upper portions of the great laccolite, whereas the lumps and expansions forming the subsidiary laccolites, of which the Quizzyhota is one, occur either along the central axis or in the lower portion. In Komgha one is, as it were, in the cellars of the giant structure; the upper stories can be seen to the north in the long table-topped hills of Cathcart. Thence to the north the sills follow each other in countless steps up to the main watershed of the country, which, for a great distance in the west, is a steep escarpment facing south, and generally some 6,000 feet above sea-level, though exceptional heights occur on the north of the Graaff Reinet Division in Compass Berg, 8,500 feet, and Middle Mount, 6,263 feet. East of Compass Berg the main watershed and the central axis of the great laccolite continue in the same direction, but the escarpment curves to the southwest. All these sills dip slightly inward to the north; they are connected by innumerable dykes and often branch and undulate in many remarkable ways. North of the main watershed all the drainage flows into the Orange River, which is held up by the bar across its lower course at the

[1] *Ninth Ann. Rept. U.S. Survey Territories*, Washington, 1877, XLV, Fig. 2.

[2] A. Harker, *Nat. Hist. Igneous Rocks*, 67; "Tertiary Igneous Rocks of Skye," *Mem. Geol. Survey of Glasgow*, Fig. 16, p. 89.

Aughrabies Falls, a little under 2,000 feet above sea-level, and the "kopje veld" of the country south of the main watershed is replaced by wide open flats and the gorges of the rivers by winding, shallow streams of low gradient. Here all the sills dip southward till the old shore line of the Karroo Lake is reached and the older basement

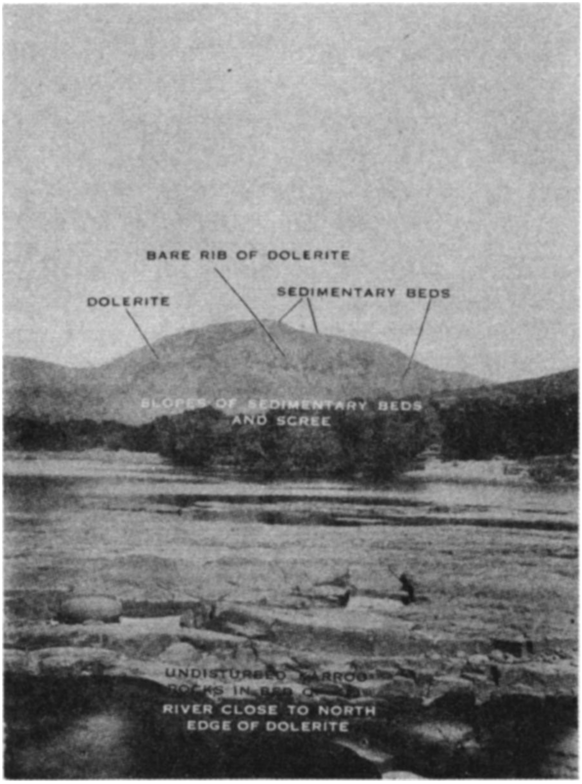

FIG. 7.—Western end of Quizzyhota laccolite, showing dolerite passing into the Karroo rocks of the Krantzes.

of the Karroo makes its appearance. Besides the main watershed there is another topographical feature to be observed: it is the main escarpment of the Karroo sediments and the dolerite sills which coincide with the main watershed in the west, but diverge from it east of Compass Berg. The escarpment begins on the east

with the Amatolas in King Williamstown Division, thence westward is continued north of Fort Beaufort as the Great Winterberg (highest point 7,800 feet), thence to the Sneeuw Bergen (Compass Berg, 8,500 feet), Koudeveld Bergen, Nieuweveld Bergen (Bulthouders Bank near Beaufort West, 6,270 feet), and finally turns round and faces southwest in the Roggeveld Mountains. Although this great ledge, capped throughout with dolerite, forms the main structural feature in the south of the colony, the rivers take no notice of it east of Compass Berg. The Fish River, especially, starts from the main watershed, although this is situated at a much lower level, and cuts great gorges in the country till it escapes to the lower country beyond the ledge. The main watershed coincides with the escarpment from the Nieuweveld to the Compass Berg; thence the escarpment proceeds in an east-northeasterly direction, whereas the watershed runs northeast by east to Delagoa Bay. The watershed is a consequence of the mode of deposition of the Karroo sediments; when these at last rose above the water-level the thickest deposit was highest and from this insignificant crest the rivers began to run over the featureless plain. The ledge or escarpment, on the other hand, is connected with the folding of the Cape Coastal Mountains, probably in a causal connection, that is to say, the dolerite caused the folding; at any rate the southern edge of the Great Karroo laccolite is parallel to the strike of the coastal mountains. The interval between the escarpment and the folded mountains is from fifty to a hundred miles, but the sills advance considerably in front of the escarpment. Thus, on the extreme east, there are the Amatolas, with the laccolite of Debe Nek in front of it, and dolerite dykes extending to points within 4 miles of the Keiskama River, a distance of 50 miles from the crest of the Amatolas, while the folded mountains lie another 50 miles to the south. However, we must regard the great ledge or escarpment as the main boundary of the laccolite and this runs in a gentle arc, with the ends east and west of each other. The center of the bend corresponds to the alteration of the strike of the Cape folded mountains from east and west, to east-southeast, which alteration occurs in Willowmore, Uniondale and Knysna.

The Karroo Beds south of the folded mountains—at least the

remnants left in the Worcester and Robertson Divisions—are not intruded by dolerite.

The great system of sills and dykes runs out to sea with the Karroo rocks near East London and comes in again with them near St. Johns. From the last place the margin runs north to Pietermaritzburg and Ladysmith, thence across the north of the Orange Free State down the Vaal River to Hope Town, Prieska and Brand Vley, thence through Calvinia to near Karroo Poort in the Ceres Division and from there to Beaufort West.

The Stormberg lavas have nothing to do with the Karroo dolerites which the volcanic chimneys pierce. Dolerite dykes indistinguishable in composition from the Karroo dolerites traverse in turn the lavas of the Drakensburg, but these latter are rather to be regarded as dykes connected with the intrusion of the lava.

The dolerite as a whole is an augite-olivine-plagioclase rock; the varieties with a little quartz in granophyric intergrowth or with mica are quite insignificant. One peculiar glassy dyke with nepheline I obtained in Beaufort West,[1] but otherwise the normal dolerite is of an intensely conservative nature. A diorite often traverses the rocks in the east at Cradock and in Komgha and Kentani.[2] These I shall have to refer to later; they are usually taken to be later injections from a primitive magma which has rid itself of the more basic substances, but I shall endeavor to prove that they are the channels down which the more acid materials absorbed by the dolerite from the country rocks are passed out.

THE PROBLEM OF THE DOLERITE INTRUSIONS

Having now established the relationship of the Quizzyhota laccolite to the dolerites of the Karroo and that of the sedimentary rocks to those forming the main portion of the Karroo, we have to inquire how a great mass of igneous rock can have come to lie within the sedimentary rocks without disturbing their stratification and without notably altering them by thermal metamorphism.

[1] E. H. L. Schwarz, "Geological Survey of the Beaufort West District," *Ann. Rept. Geol. Comm., 1896,* Cape Town (1897), 18.

[2] A. W. Rogers and E. H. L. Schwarz, "General Survey of the Rocks of the Southern Transkei," *Ann. Rept. Geol. Comm., 1901,* Cape Town, 1902; "The Transkei Gap," *Trans. Phil. Soc. S. Africa,* XIV, Cape Town, 1903.

The arguments employed here rely on the theory that igneous magmas are solutions not necessarily at very high temperatures. I shall endeavor to establish the fact that such magmas—which in their injection state may be entirely fluid or may consist more or less of crystals already formed, but yet, as a whole, plastic under pressure with the help of solvent water—have certain properties which cause them to crystallize in one standard type with structure and composition constant, no matter what amount of extraneous rock they may have absorbed. I shall apply to a rock magma and the resulting igneous rock the laws which govern the development of single crystals, such as andalusite, in among rocks of totally different composition, assuming that what holds good for individual crystals, also applies to collections of crystals such as igneous rocks are.

The argument will be, in short, that the original molten or fluid magma works its way up into the rocks near the surface of the earth; the release of pressure sets free a certain equivalent of heat, or more probably chemical activity, which is employed in absorbing the rocks encountered. As portions of the country rock become digested, the bulk of the igneous rock at any one time preponderates over the including fragments, and the mineral composition of the magma asserts itself in that it takes from the fragments it is absorbing such substances as are suitable to the formation of the rock of the type represented by the magma, and unsuitable material is passed downward along the supply dykes. Dykes consolidated before the waste material has been removed are represented in the dolerite dykes of the Rainy Lake region in Canada; for instance, the White-Fish Bay dyke, where the outside is a fine-grained dolerite with 47.8 per cent silica, while the inner side is a quartz hornblende rock with 52.5 per cent silica. These dykes are very wide, 120 to 150 feet. In smaller dykes the up-and-down current appears to have been too rapid for the consolidation to catch the two before the completion of the process. Nevertheless, the composite dykes of Arran are of the same nature, although of different origin. The evidence for this argument afforded by the Quizzyhota laccolite will be given in the sequel; it is necessary first to outline the evidence afforded by the development of single crystals such as anda-

lusite and to show how closely the phenomena exhibited by the larger masses, the igneous dykes and laccolites, are presented by the individual crystals.

THE DEVELOPMENT OF ANDALUSITE CRYSTALS

The development of crystals of andalusite, chiastolite, cordierite, and staurolite is most beautifully illustrated in the rocks round the Great Transvaal laccolite. The metamorphic rocks have been described by Hall[1] and I am greatly indebted to him for supplying me with material for study from this locality. The andalusite substance in the less advanced types settles as irregular patches in the shales, schists, sandstones, or whatever type of sedimentary rock is becoming metamorphosed. The minerals of the original rock are, as it were, pushed aside to make way for the introduction of the new material and no absorption is at first apparent. In more advanced types the minerals of the original rock are seen to be whittled away; usually there is an outer zone where the andalusite crystal is more or less free from inclusions. The developing crystals all tend to form in about the same dimensions in the particular rock-type and it is a constant feature that the prism zone early asserts itself, the planes bounding the long axis of the crystal being quite sharp, whereas the basal planes are indefinite, at any rate in the Transvaal specimens that I have seen and in those described by Hall. The Transvaal andalusites apparently do not go beyond this stage, but the smaller variety of the substance, chiastolite, does form very definite, sharply bounded crystals. The section illustrated by Hall (*Survey Report*, Part I, Fig. 1) shows the developing chiastolite with the center still full of inclusions, the outer rim clear, and the complete crystals in which all but a small string of inclusions in the center has been cleared away.

For the later stages of the development of andalusite I will take the andalusite schist of George.[2] The occurrence is on the Zwart

[1] A. L. Hall, "The Geology of the Haenertsburg Gold Fields," *Report Geol. Survey, 1907*, Pretoria (1908), 43 ff.; "Contact Metamorphism in the Western Transvaal," *Trans. Geol. Soc. S. Africa*, Vol. XII, Johannesburg (1910), 119.

[2] E. H. L. Schwarz, "The Andalusite Schist of George," *Albany Mus. Records*, II, 164 (1907), Grahamstown.

River along the main road from George to Knysna, about 5 miles from the former place; there is a small granite dyke exposed on the road section piercing the mica schists belonging to the Malmesbury Formation; about 5 yards from the granite the rock suddenly becomes full of well-formed andalusite crystals about an inch in length. The crystals are coated with scales of mica and usually have drawn out extremities in which mica flakes and andalusite substance have not yet become separated; some crystals, however, are sharply terminated. At the actual contact there is a thin zone of Cornubianite, never more than an eighth of an inch in width, in which there are small crystals of andalusite averaging .7 mm. in length and .15 mm. in breadth. Eye-shaped patches of the same substance occur where the schist has been kinked, and both crystals and "eyes" contain pellucid egg-shaped grains of quartz and a little red-brown mica, all that is left of the original sand grains and mica-flakes of the original rock. Occasionally a mica-flake of the schists ends abruptly at the margin of the andalusite, and in the latter there is the continuation of the flake rounded off in the usual manner of these inclusions; the flake has the appearance of having had its end melted and a portion incorporated in the new crystal of andalusite. When the crystals of andalusite have sharp ends, the dome faces are not equally developed on either side of the end; they follow the sides of the original kink of the shale in which the substance has been deposited, as if the crystal were monoclinic—another instance of the feebleness of the crystallizing force in the terminations as compared with the sides.

The larger crystals may be divided into the perfect forms and the irregular ones. In a longitudinal section of the former the substance of the andalusite is transparent with the usual pleochroism. Trains of rounded black dots and stout, short rods of rutile follow more or less the direction of the planes of parting. The black dots are graphite showing in reflected light an adamantine luster with white faces; they are probably carbonaceous matter that has aggregated in the andalusite substance from the flocculent material in the schists. The rutile needles also appear to have been enlarged from the minute ones in the biotite flakes. Rounded flecks of red-brown mica occur throughout the substance as well as the egg-

shaped pellucid quartz grains; these are the remnants of the minerals of the schists digested and almost absorbed. In the irregular crystals trains of unaltered mica-flakes pass right across the prisms, but in the perfect crystals these "segregation bands," as they would be called in igneous rocks, have been broken up and digested in the main. In many sections, however, little rounded specks occur which, under the microscope, appear as little xenoliths of the country rock. The andalusite, unable to penetrate and rid itself of these remnants, has tied up the indigestible substance in little rounded pockets, which may be as much as 1 mm. in diameter.

The andalusite substance apparently came from the granite, because it occupies spaces originally taken up by minerals of varying composition; some of the substance of the matrix has undoubtedly contributed to the building up of the andalusite crystals, but the part represented by the potash, iron, and magnesium of the biotite and by the potash of the muscovite must have been replaced by new material. There is further reason for believing that the new substance came from the granite, because in Stellenbosch, under precisely similar conditions, large feldspar crystals develop. Now the granite at George is a muscovite granite and would want all the potash for its own minerals, and therefore passed out aluminium silicate, but the Stellenbosch granite is a biotite granite and therefore could spare the potash, hence it passed out potash aluminium silicate.

THE ACID RESIDUE AFTER ABSORPTION

It will be evident from an inspection of the photographs accompanying this paper that the sediments have been dissolved by the dolerite, and from the analyses given it is apparent that the siliceous residue has been removed. Where has it gone to? As there are only channels of communication downward, the answer is that the siliceous material has gone toward the deeper portions of the earth's crust and there solidified. The granite bosses of the western province of Cape Colony represents the siliceous residues; they originally had Karroo sediments above them, probably with dolerite intrusions. In the Cape Town granite there are dolerite dykes associated with the granite, which go right up through the Table

Mountain sandstone.[1] I do not, however, wish to include in this discussion the question of the granite bosses as I have no new studies on them to offer, but the evidence for the absorption of sediments is very plain, especially along the granite contact at Sea Point, which was used by Hutton in illustration of his principles, and at Robertson, where the granite is bordered by a rim of *lit-par-lit* injection and other phenomena that I believe will afford positive evidence for the part these masses played in the general igneous injection of the country, when the material is worked up.

The igneous rocks of Cape Colony are very simple—enormous tracts of dolerite above and granite below; there are none of the complicated varieties to obscure the main principles. There is a curious side-issue in respect to the injection of andalusite crystals or occasionally orthoclase crystals in the sediments round the granite.[2] I assume for the purpose that the evidence for the absorption of sediments by the granite is as complete as for the dolerite, at least in Cape Colony, and that the original magma plus the material absorbed separated into dolerite and granite. We do not at present know what the proportions of basic and acid rock were, but we can suppose that they were equal. If, now, we take the mean of any analyses of normal granite and dolerite and contrast it with the analysis of any non-calcareous slate, adding a little sandstone if the silica percentage is small, we shall find that the excess of material after the igneous rock has used up all it wanted, consists of silica, alumina, and potash, and naturally, if the igneous rock is locally rich in potash, then of silica and alumina only. That is to say, the very general injection of silicate of alumina in the form of andalusite, chiastolite, and sillimanite, and the fairly common injection of orthoclase crystals, would be a result of the absorption of the slates and the rejection by the granite-dolerite magma of waste material. I take as an illustration the analyses given in Professor Judd's *Students' Lyell*, which can easily be checked. A more suitable series of analyses would be the slates intruded by the granite, the granite and the dolerite dykes in the granite, which

[1] See F. H. Hatch and G. S. Corstorphine, *Geology of S. Africa*, Figs. 2 and 3; pp. 37 and 41.

[2] E. H. L. Schwarz, *Ann. Rept. Geol. Comm.*, *1897*, Cape Town (1899), 54.

occur on the Wynberg side of Table Mountain, but I have not the material before me; a large number of similar series of analyses that I have tried give the same result.

	Granite	Dolerite	Mean	Mica-Schist	Excess after Absorption
S_iO_2	76.1	50.2	63.1	66.2	3.1
Al_2O_3	13.4	15.0	14.2	18.6	4.4
$FeO_iFe_2O_3$	1.3	16.9	9.1	5.3	...
MgO	.2	5.8	3	1.2	...
CaO	.3	10.5	5.4	.4	...
Na_2O	3.1	2.2	2.6	2.2	...
K_2O	4.9	1.4	3.1	3.9	.8

THE RESEMBLANCES BETWEEN THE DEVELOPMENT OF ANDALUSITE CRYSTALS AND IGNEOUS INJECTION

In the case of the George andalusite we have a crystal substance injected into a rock. It first occupies cavities ready made for it, then with accession of further material, it dissolves, or as we should say in speaking of igneous rocks, melts up portions of the invaded rock, assimilates suitable substances and passes out the residue. Segregation bands develop where conditions are unfavorable, and included blocks or xenoliths entirely unaltered or more or less "metamorphosed" occur. All the phenomena of igneous injection are portrayed without the aid of any great heat, though hot water circulating under pressure was no doubt the agent by which the transference of material was accomplished. In the constancy of size also the masses of igneous rocks are simulated. The Zwart River crystals are about an inch in length—4 cm. perhaps would be the best average. None are much smaller or larger. A little farther on a similar but less perfect development of crystals occurs where the size is half that of those of the Zwart River material, and again in the chiastolite slates of the Transvaal a much smaller average is attained. So throughout the Karroo the dykes and sills are very constant in thickness; the laccolites of the Drakensberg Plateau and the granite bosses of the southwest are of approximately equal bulk. The granite masses of Cornwall and Devon are another striking example. It would seem that as with crystals so with magmas, there is a limit of size.

THE CHANNELS BY WHICH THE ACID RESIDUES ESCAPED

The escape of siliceous material from the dolerites should leave somewhere some trace. As the channels of supply function at the same time as conduits for the waste material, there should exist occasionally composite dykes of the type described from Canada by Lawson,[1] and from Norway by Vogt,[2] which have basic margins and granite or syenite centers. Similar ones occur in Arran consisting of selvages of augite-andesite and centers of quartz-felsite as described by Judd.[3] They have also been found in Skye and the Thüringer Wald.[4] No dykes of this nature have so far been noticed in South Africa, but diorite dykes genetically related to the dolerite sills are fairly common about Cradock and Kentani. A pair of parallel dykes in the Transkei were described by Dr. Rogers and myself in 1901; they run a little north of the Quizzyhota, cross the Kei, and traverse the Kentani district to its eastern border along the Kogha River; the easy weathering of this rock as compared to that of the dolerite and Karroo sediments has left deep furrows in the land, which have been given the local name of the "Transkei Gap."[5] Another diorite mass occurs at Gonubie along the main road from Kei Road to Komgha. The Gap-rock was described by Dr. Rogers in the paper referred to, and I reproduce it for comparison with the description of the dolerite of the Quizzyhota.

The rock forming the dykes of the Gap is a peculiar one, differing in important respects from any intrusions hitherto found by us in the Karroo Formation, although as will be pointed out in the following notes, it has a distinct relationship to the olivine-dolerite of the sheets.[6] It consists chiefly of the following minerals in the order of their usual relative abundance: plagio-

[1] A. C. Lawson, *Report on the Geology of Rainy Lake Region, Geol. and Nat. Hist. Survey, Canada* (Ann. Rept., 1887–88), Part F.

[2] J. H. L. Vogt, *Geol. Mag.* (1892), 82; W. C. Brogger, *Eruptivgesteine des Kristianiagebietes*, I (1894), 56.

[3] J. W. Judd, "Composite Dykes in Arran," *Q.J.G.S.*, XLIX, 545 ff.

[4] A. Harker, *Tertiary Igneous Rocks of Skye*, chap. xii.

[5] A. W. Rogers and E. H. L. Schwarz, "The Transkei Gap," *Trans. Phil. Soc., S. Africa*, XIV. (Cape Town, 1901), 63.

[6] The olivine-dolerite which forms the intrusive sheets of the Transkei is very like the rocks occurring in the same manner near Beaufort West, and described by E. Cohen, *Neues Jahrb.* (1874), 195.

clase, hornblende, augite, quartz, red-brown mica, orthoclase, apatite iron ores, sphene and decomposition products such as chlorite, uralite and calcite. Variations in the proportions of these minerals show that the rock differs considerably in composition from point to point.

The plagioclase has almost always a zonal structure; . . . . it frequently shows crystal outlines when in contact with the hornblende and augite, sometimes small crystals of the feldspar are entirely inclosed by the hornblende and augite. This ophitic structure though found without difficulty in all slices of the rock examined, is not nearly so pronounced a feature as in the olivine-dolerite.

The original hornblende is mostly of a pale greenish-brown colour, with feeble pleochroism, but a bright green strongly pleochroic variety also occurs, sometimes forming part of a crystal which is mostly made up of the pale kind. Occassionally small crystals showing the prism faces are met with, but the larger plates seen in the slices are always irregularly bounded by contact with other minerals, notably plagioclase. The last remark applies also to the augite, which is colourless in section and appears to be identical in character with the augite of the olivine-dolerite. The hornblende and augite usually occur together, intergrown with their orthopinacoidal faces parallel. The augite often forms the inner part of a section of the two minerals; outside this area the hornblende encloses the whole. The structure is easily seen by ordinary light under the microscope, as the augite is colourless and the hornblende pale greenish-brown, but between crossed incols the minerals are still more clearly seen owing to their extinguishing in different positions of the nicols. The intergrowths of the two minerals are sometimes twined, the composition plane being the ortho-pinacoid, common to both minerals.

Hornblende is rarely found in the olivine-dolerites but it does occur in them, *e.g.*, in the coarse olivine-dolerites of the sheet seen on the shore between the Gxacha and Kologha Rivers (Kentani) and in the Kologha sill. In a slice from the dolerite sill exposed along the Kei River at Mimosa Hill (the Kologha sill) there is much hornblende of the same variety as that in the Gap-rock and it is also intergrown with augite.

The mica is a red, strongly pleochroic variety, frequently altered to a very pale, greenish mineral with weak double refraction. It frequently encloses small zircons round which there is always a pleochroic halo; zircon occurs similarly in the hornblende. This mica occurs frequently and is a most important constituent of the Gap dykes; a precisely similar variety is found in almost all slices of the Transkeian olivine-dolerites but in very small quantity.

Quartz is abundant in some parts of the Gap dykes and present in all slides examined. It was the latest constituent to crystallise out from the liquid magma; it frequently forms a micropegmatitic intergrowth with a cloudy untwined feldspar which is probably orthoclase. Both micropegmatite and quartz are occasionally seen in the slices of the dolerites, but they are generally very subordinate constituents of the rock.

The iron-ores are magnetite, ilmenite with which sphene is often associated and iron pyrites. Apatite is always present, sometimes in considerable quantity.

The rock forming the dykes of the Gap may be called quartz-mica-augite diorite; it differs from the olivine-dolerite very considerably in the absence of olivine and in the presence of large amounts of hornblende, brown mica and quartz as well as the more acid varieties of plagioclase. It is very noticeable, however, that none of the minerals which characterise the Gap-rock are foreign to the olivine-dolerites and in the case of the Kologha sill the dolerite in parts approaches the Gap-rock in character rather closely by the increase in the amount of hornblende, red mica and the zoning of the plagioclase. The affinity between the two rocks is sufficient to make it preferable to regard the Gap-rock as derived from the magma which supplied the dolerite intrusions rather than the result of a quite different order of events. If we consider the Gap-rock as a late product of the magma after the dolerite had been got rid of, our view will explain the facts observed under the microscope and in the field; for while the evidence of a microscopic examination shows that the Gap-rock and the dolerite are genetically related, the field evidence conclusively proves that the latter rock had solidified before the former was intruded through it.

I do not think the last-mentioned fact invalidates the present view that these diorite dykes are the channels of escape of waste siliceous material as well as supply dykes of basic material. The dolerite spreads upward and the conduits of the upper sills must have remained open after the consolidation of the lower sills. There has been noted also a sequence in the infillings of the composite dykes of Arran and Skye. It may be noted that in the latter locality, where the granite invades the gabbro, it often partially fuses it and converts it into a rock consisting of hornblende and feldspar (labradorite to oligoclase).[1] At any rate the absorption of the sediments by the dolerite necessitates the escape of siliceous material, and the diorite dykes, where the differentiation into an acid and basic series has not been completed, are of the necessary constitution. The fact that the diorite dykes have been noticed where there is great development of laccolites, as at Cradock and in Komgha, is of special importance. The ordinary sills of the Karroo have been intruded for miles along inclined planes and, as the thickness of the dykes and sills varies very little, the diffusion of the acid and basic parts of the magma would have been unrestrained. In the laccolities, however, which form great lumps with

[1] A. Harker, *Tertiary Igneous Rocks of Skye*, 171.

comparatively narrow supply dykes, the channels of supply and escape of waste siliceous material are so small that the diffusion of the substances in the magma would have been hindered and as a result these dykes consolidated with rocks of the average composition.

THE DIFFUSION DUMBBELL

Taking the whole evidence which the granite bosses, the diorite dykes and the dolerite laccolites afford us in Cape Colony, one is led to conceive of a system of igneous injections of a dumbbell shape. Below we have the Malmesbury clayslates, above the Karroo sediments, in between the various siliceous sediments of the Cape system, or sometimes in the north of the Pal-Afric group Kheis quartzites and Pretoria iron-bearing quartzites. Below, the magma eats out great holes and fills them with granite; above, the same magma eats out the holes and fills them with basic rock. In between are thin dykes of communication usually dolerite but uuder certain conditions diorite. The slates above and below became absorbed and the material from both was added to the general stock of magma. The average magma remained fluid in this dumbbell system for some time, till for some reason the acid part concentrated in the lower part and the basic in the upper part, the diffusion taking place through the narrow part of the dumbbell and sometimes the average magma became caught in this part and became consolidated as diorite.

The facts are plain enough and it is perhaps as well to content oneself with them at present, but there is an explanation which, if only speculative, may be worth mentioning in order to show that this differentiation of an average magma is not wholly unexpected.

THE IONIC SEPARATION OF SUBSTANCES IN A ROCK-MAGMA

When an iron-bearing rock weathers at the surface of the earth, the iron does not travel outward to the sea along with the soda, lime, and potash but seeks the center of the earth.[1] The fact is easily recognizable in the replacement of limestone by iron ores,

[1] E. H. L. Schwarz, *Causal Geology* (1910), 73; "Selective Absorption of Substances in the Earth's Crust," *Journal Assoc. for Advancement of Science, S. Africa* (Cape Town, 1912), 181.

which are of common occurrence; in these cases certain conditions have caused precipitation of the iron from solution, but where the conditions are not favorable, the iron goes on its journey downward toward the base of the crust. Weak solutions such as these which carry the iron are ionized and the metallic ion carries a positive charge of electricity; the metallic ion possibly is attracted by the magnetic core of the earth, but however that may be, the iron goes down and must come to rest in the base of the crust beyond which water cannot penetrate. This would lead to an accumulation of a positive charge at the base of the crust. Above this is suspended a solution or a fluid magma which is an electrolyte,[1] that is, one in which the substances are ionized and the metallic ions carry a positive charge and the acid ions a negative one. Under such circumstances the negative, acid ions would be attracted by the positive charge at the base of the crust and the metallic, positive ions would be repelled, and in that way a magma of average composition would be differentiated into an acid and basic series, the acid part accumulating in the lower half of the dumbbell and the basic in the upper. Whether this cause is sufficient for the effect I do not know, but considering the immense time during which geological phenomena take place, a small but persistent electrical attraction and repulsion, such as exists under the circumstances, would have far-reaching effects.

[1] C. Barus and J. P. Iddings, *Amer. Jour. Sci.*, XLIV, 242.